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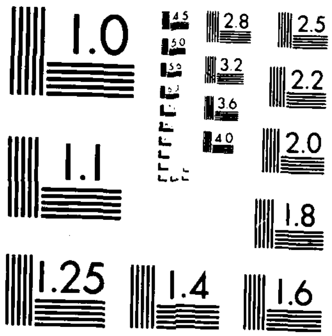
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HUMAN RESOURCES

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FLIGHT SIMULATOR: FIELD OF VIEW UTILIZED IN PERFORMING TACTICAL MANEUVERS

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Frank T. Vaccaro, Capt, USAF

OPERATIONS TRAINING DIVISION
Williams Air Force Base, Arizona 85240-6457

April 1988
Final Paper for Period January 1983 - December 1984

LABORATORY

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Chief, Operations Training Division

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This paper describes the field of view (FOV) used by experienced fighter pilots (F-16 instructor pilots) in a flight simulator to perform specific air-to-air and air-to-ground maneuvers. Flight simulators, driven by technology, have evolved into complex training systems. Accurate use of this technology requires that parameters be specified for each type of task to be performed in a flight simulator. Due to cost, one important parameter to specify is the FOV required in the simulator visual display. FOV research has been done for tasks such as basic contact maneuvers, takeoffs, and landings. A single-window (48° x 60°) visual system was found to be adequate to perform and train these tasks in a simulator. Most operational flight training simulators have this type of visual system for training such maneuvers. Recently, operational commands have become interested in expanding simulator training to include more advanced tasks such as tactical maneuvers. In this effort, the Air Force Human Resources Laboratory provided assistance and guidance to Tactical Air Command (TAC) in the measurement of the FOV utilized in performance of 14 offensive tactical maneuvers.

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Maneuvers evaluated for air-to-air were the Lo Yo-Yo, Hi Yo-Yo, Immelmann, Quarter Plane, Lag Roll, Lead Turn, and Barrel Roll. Air-to-ground maneuvers were the Level Bomb, 10° and 30° Pop-Ups, and 10°, 15°, 30°, and 45° Dive Bombs. FOV measurements were taken in the Simulator for Air-to-Air Combat for the air-to-air tasks and in the Advanced Simulator for Pilot Training for the air-to-ground tasks. Air-to-ground tasks were performed in both a wide (full) field of view (WFOV) and a limited field of view (LFOV).

Data collected on the FOVs utilized suggest that the requirements for air-to-air tasks are different than those for air-to-ground tasks. In nearly all cases, the FOV utilized for air-to-air tasks was larger and was symmetrical about all four directions (right, left, up, and down), whereas the FOV used for air-to-ground tasks was smaller and skewed to the left and down. The total FOV utilized when performing the air-to-air tasks was 177° x 133°. The Lo Yo-Yo utilized the smallest area, 74° x 80°, while the Quarter Plane utilized the largest area, 150° x 133°. For the air-to-ground tasks, the Level Bomb used the smallest area, 60° x 64°; and the 30° Pop-Up used the largest area.

The size and shape of the FOV utilized were directly related to the task being performed, ranging from -60° x 2° x 56° x -11° (left, right, up, and down) for the Level Bomb task to -105° x 57° x 80° x -63° for the Quarter Plane task. This indicates that limiting the pilot's FOV creates a task-specific condition, if the target is to remain in the pilot's FOV. The variability of the FOV for each task leads to the conclusion that placement of the FOV will be an important criterion in developing an LFOV simulator. Thus, specifying one optimal LFOV for all tasks to be performed or trained in an operational flight simulator will be difficult, if not impossible, especially if both performance and cost are considered. Although measuring the FOV used in the performance of specific tasks provides a starting point for limiting the FOV, it must be determined if the use of an LFOV degrades pilot performance. During this study, a proposed LFOV was tested during performance of the air-to-ground tasks. Compared to the LFOV, the WFOV produced signficantly more accurate bomb scores and significantly lower bomb release altitudes. Another noticeable performance difference in the LFOV condition was a tendency of the pilots to turn tighter into the target. Analyses of target migration data indicated a significant difference in the LFOV condition. These data will provide a baseline for future FOV research and will give TAC a guideline as to the FOV utilized in tactical maneuvers.

AFHRL Technical Paper 87-50 April 1988

FLIGHT SIMULATOR: FIELD OF VIEW UTILIZED IN PERFORMING TACTICAL MANEUVERS

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Reviewed and submitted for publication by

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Chief, Technology Development Branch

This publication is primarily a working paper. It is published solely to document work performed.

SUMMARY

This paper documents the field of view (FOV) utilized by experienced fighter pilots when performing specified portions of air-to-air and air-to-ground maneuvers. The FOV measurements were taken in the Simulator for Air-to-Air Combat (SAAC) and the Advanced Simulator for Pilot Training (ASPT). During the air-to-ground data collection, measurements were also taken while subjects performed the same tasks with a limited field of view (LFOV). Results of the data collected indicate that the FOV utilized varied widely between air-to-air and air-to-ground maneuvers. In nearly all cases, the FOV utilized for air-to-air maneuvers was symmetrical and that for air-to-ground maneuvers was skewed to one side. When air-to-ground tasks were performed in an LFOV, significantly poorer bomb scores and significantly higher release altitudes were found when compared to wide-FOV performance. A noticeable performance change in the LFOV condition was a tendency of the pilots to turn tighter into the target. The true effect of this change in flight path still needs to be investigated. Specifying one optimal LFOV for all maneuvers to be performed or trained in an operational flight simulator would be difficult if both cost and performance were to be considered. The variability of the FOV leads to the conclusion that placement of LFOV will be an important decision when considering what tasks will be performed. Full training implications cannot be determined until further transfer-of-training experiments are completed.

PREFACE

This work was performed in support of a request by the Tactical Air Command Directorate of Training. Support provided by the Air Force Human Resources Laboratory was provided under Technology Planning Objective 3, the thrust of which is aircrew training. The general objective of this thrust is to identify and demonstrate cost-effective training strategies and training equipment capabilities for use in developing and maintaining the combat effectiveness of Air Force aircrew members. More specifically, the research was part of that conducted under the Air Combat Training subthrust, which has as its goal the development of instructional innovations in Air Force flying training. Work Unit 1123-37-01 (previously 1123-02-59), Tactical Warfare Training Research, addressed a portion of this subthrust; namely, evaluating the field of view required to perform specific air-to-air and air-to-ground maneuvers. Data collected during this research will be used as a baseline for follow-on research under Work Unit 1123-32-04, Simulator Field-of-View Requirements in the Training Effectiveness Area. Mr. Lynn Thompson was the project monitor, and Captain Linda Wiekhorst was the principal investigator.

The conduct of this research depended heavily on the assistance and participation of several people. The engineering development necessary to conduct research on the Advanced Simulator for Pilot Training was completed by Mr. Brett Butler and Mr. Nelson Ludlow, who worked many hours on a short-notice project. Lt Col Bart Raspotnik conducted the air-to-air data collection and provided support for the development of tactical situations. Mr. Russ Techlow performed the engineering development for the Simulator for Air-to-Air Combat. Particularly worthy of thanks are the F-16 pilots from the 58th Tactical Training Wing, Luke AFB, Arizona, who participated as subjects. Invaluable assistance in data reduction and analysis was provided by Mr. Richard Greatorex and Sgt Bernadette Hill.

This technical paper supersedes an earlier version (AFHRL-TP-86-29), which used a split plot factorial analysis of variance for data analysis. This revision uses a multivariate randomized block factorial as the analysis of variance model. The results of this reanalysis indicate that subjects flew significantly lower and had significantly more accurate bombs in the wide-field-of-view condition than in the limited-field-of-view condition. Field of view did not significantly influence either airspeed or dive angle.

The revision was accomplished by Herbert H. Bell, a research psychologist at the Operations Training Division.

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FLIGHT SIMULATORS: FIELD OF VIEW UTILIZED IN PERFORMING TACTICAL MANEUVERS

I. INTRODUCTION

Statement of Problem

A critical concern within the flight training research and development (R&D) community and operational commands is the field of view (FOV) available in flight simulators. Operational commands need to minimize the cost of simulators and still provide effective training. The cost to achieve equivalent levels of resolution and scene detail for a wide-field-of-view (WFOV) simulator visual system (300° x 150° or more) can be many times the cost of a typical single-window system (approximately 48° x 36°). However, the potential training effectiveness of limited-field-of-view (LFOV) simulator visual systems still needs to be identified. Thus, R&D is needed to identify how much FOV will allow the required tasks to be accomplished without creating a degradation in performance. The flight training R&D community has conducted research, both in the aircraft and in simulators, on the FOV necessary to train and perform takeoffs, landings, and basic contact maneuvers. Irish, Grunzke, Gray, and Waters (1977) concluded that instrument flying, emergency procedures training, and basic contact maneuvers can be taught in flight simulators using an LFOV as small as 48° x 36° (single-window). Research on the performance of more advanced flight maneuvers in an LFOV has been sparse and requires more attention.

Currently, Tactical Air Command (TAC) is in the process of funding an F-15 Operational Flight Trainer and has stated a training need for LFOV visual systems. Inputs were needed for the FY 1986 Program Objective Memorandum to select the most efficient fixed-LFOV system. TAC is currently considering the procurement of a visual system having dimensions of approximately 160° x 60°. In response to this need, TAC requested the 57th Fighter Weapons Wing to provide preliminary observations to define the FOV required to perform specific air-to-air and air-to-ground tactical maneuvers. In support of this request, the Operations Training Division of the Air Force Human Resources Laboratory (AFHRL/OT) provided resources and guidance in conducting an investigation to determine the FOV required to perform a specified set of air-to-air and air-to-ground tasks in a flight simulator. It was also possible to analyze the effect of limiting the FOV when the air-to-ground offensive maneuvers were performed.

Research conducted under this effort was structured to determine the FOV used in the performance of seven simulated tactical bombing maneuvers and seven simulated air-to-air maneuvers. The air-to-air maneuvers evaluated were Lo Yo-Yo, Hi Yo-Yo, Immelmann Attack, Lag Roll, Lead Turn, Barrel Roll Attack, and Quarter Plane. Air-to-ground maneuvers included Level Dive Bomb, 10° Dive Bomb, 15° Dive Bomb, 30° Dive Bomb, 45° Dive Bomb, 10° Pop-Up, and 30° Pop-Up. These maneuvers represent approximately 70% of the air-to-ground conventional range tasks and 100% of the basic offensive air-to-air maneuvers, according to the Required Operational Capability task list for F-16 aircraft. Air-to-air maneuvers were performed in the Simulator for Air-to-Air Combat (SAAC), and air-to-ground maneuvers were performed in the Advanced Simulator for Pilot Training (ASPT).

The data collected provided an estimate of the FOV dimensions that a pilot will actually use when performing the specified tasks. These data will subsequently be utilized as a baseline for future FOV R&D in the training effectiveness area.

Field-of-View Research

A review of literature dealing with FOV research reveals that numerous experiments have been performed using fixed and variable FOVs of various sizes and orientations. Major conclusions drawn from the research are: (a) flying tasks can be performed with an LFOV or area of interest (AOI) in the aircraft or simulator; (b) a primary consideration of using an LFOV is the placement of the FOV, creating many task-specific conditions; and (c) in a turning task, subjects tend to make tighter turns in the LFOV than in the WFOV condition. Most FOV research was done using tasks that require the pilot to look primarily straight ahead. Tasks of this nature include takeoffs, landings, and basic flight maneuvers. Limiting the FOV for these types of tasks results in the loss of peripheral information that pilots use for landmarks.

Several in-flight studies using an LFOV have shown that takeoffs and landings can be accomplished safely by experienced pilots. FOV dimensions of 10° horizontal x 10° vertical, 21.5° horizontal x 21.5° vertical, and 57° horizontal x 30° vertical are some of the dimensions studied. Collyer, Ricard, Anderson, Westra, and Perry (1980) summarized this in-flight research and indicated that performance of takeoffs and landings was within the safe and acceptable range, even when the FOV was restricted to less than that provided in the narrow-angle visual systems of current simulators.

Simulator studies by Irish et al. (1977) using a 36° horizontal x 48° vertical LFOV and 300° horizontal x 150° vertical WFOV showed no significant differences in the performance of takeoffs or landings between the two FOVs. However, Irish et al. (1977) also investigated the effects of FOV on the performance of three basic contact maneuvers: the Barrel Roll, Aileron Roll, and 360° Overhead Pattern. The Aileron Roll was the only maneuver with significantly better performance in the WFOV condition. Irish suggested that the dependence on precise rotational movement around the longitudinal axis of the aircraft, required in performing an Aileron Roll, was degraded in the LFOV condition, whereas the WFOV provided additional information regarding the bank position of the aircraft. He further concluded that, in the other tasks, the additional cue information provided by the wide visual display was either not particularly vital or could be acquired from other sources (e.g., instruments). In a later study, Irish and Buckland (1978) looked at pilot performance for the same five maneuvers and included an intermediate FOV (144° horizontal x 36° vertical). Results of this study found significant effects in the performance of the Aileron Roll (substantiating earlier results) and the Barrel Roll. Performance measures most strongly affected by changes in FOV related to the roll dimension of the aircraft. All of the studies discussed thus far used experienced pilots to perform these basic maneuvers, takeoffs, and landings. In a study by Nataupsky, Waag, Weyer, McFadden, and McDowell (1979), two FOVs were used as conditions in a transfer-of-training study using student pilots. Either a WFOV (300° x 150°) or LFOV (48° x 36°) was used to train four tasks: takeoff, steep turn, slow flight, and landing. No performance differences were found between the students trained in the LFOV condition and those trained in the WFOV condition when tested in the WFOV, nor was any effect evident on subsequent performance in the aircraft. Nataupsky et al. (1979) therefore concluded that an LFOV provides sufficient cueing for training the basic contact skills normally included in Undergraduate Pilot Training. This is consistent with previous studies on the performance of basic contact maneuvers in an LFOV condition.

Woodruff, Longridge, Irish, and Jeffreys (1979) used an LFOV optimally placed for takeoff and landings to determine if this same FOV could be used to perform an aerial refueling task. Four different LFOVs, corresponding to four different aircraft requirements, were used: F/FB-111 (170° x 36°), F-4 (115° x 49°), B-52 (48° x 38°), and A-10 (44° x 35°). Results indicated that B-52 and F/FB-111 pilots could satisfactorily perform takeoff, landing, and aerial refueling with the specified FOV. The A-10 and F-4 pilots, however, had to adjust the FOV +12.3° and +12.5°, respectively, in order to perform the aerial refueling. However, with the adjusted FOV, they

could not take off or land effectively. Performance of all tasks was more effective in the WFOV condition for all aircraft. These results indicate the importance of placement of an LFOV and suggest that limiting the FOV will produce a task-specific condition. In 1980, Collyer et al. investigated the effect of FOV on training a carrier landing task, using the circling approach and landing. A WFOV (300° x 150°) and an LFOV (48° x 36°) were used. The LFOV group showed a tendency to make tighter turns than did the WFOV group. Although large performance differences were seen between groups during training, when tested with the WFOV, no significant performance differences were found.

Up to this point, the research that has been discussed used a fixed LFOV with basic-contact-maneuver-type tasks. An alternative approach to the fixed FOV, is the AOI, or variable FOV, in which the specified LFOV is slaved to the subject's head position. LeMaster and Longridge (1978) used AOI sizes of 52° x 38°, 70° x 70°, 90° x 90°, 110° x 70°, and 130° x 70° to evaluate the 30° Dive Bomb task. A significant degradation in bombing performance was found only for the smallest FOV (52° x 38°), although a negative trend of performance was evident in the 70° x 70° condition. Results of this effort suggest that gunnery range and tactical bombing tasks can be effectively performed in a limited AOI.

II. WIDE FIELD OF VIEW

Objective

This experiment was conducted to determine the FOV required in a flight simulator to perform various air-to-air and air-to-ground tactical maneuvers.

Air-to-Air

Method

Subjects. Five F-16 instructor pilots, assigned to the 58th Tactical Training Wing (TAC), Luke AFB, Arizona, served as subjects. Each of the subjects had completed a tour in the F-4 aircraft, transitioned to the F-16, and was currently assigned as an F-16 instructor pilot. All were qualified as "combat ready" and were current in weapons delivery tactics and procedures. These pilots had an average of more than 2,000 total flight hours, of which approximately 1,200 were in fighter-type aircraft. They had an average of 631 hours in the F-4, with a range of 336 to 800 hours.

Equipment. Air-to-air tactical maneuvers were conducted in the Simulator for Air-to-Air Combat (SAAC), which is a Vought Corporation, fixed-base, air combat simulator, located at the 57th Fighter Weapons Wing/Operating Location AA, Luke AFB. The SAAC has two, fully interactive, F-4-configured cockpits with full instruments and weapon systems indicators necessary for air-to-air combat simulation in a functional mode. The visual system of the SAAC is comprised of eight windows within a 16-foot-diameter dodecahedron. A hardware image generation system provides a "checkerboard" ground, the sun, sky, and a low-altitude haze layer. The aircraft target image is provided by four closed-circuit television pictures of gimbaled model aircraft displayed on the earth/sky background by means of a small raster inset. Simulator realism includes on-line firing and hit cues, engine noise, g-cues, and weapons sounds. Weapons realism extends to the heat and radar missiles, as a miss will be scored if the aircraft target exceeds the missile turning/tracking capabilities before the time of flight has elapsed. The g-cueing was not used for this study.

Task Descriptions. During the air-to-air portion of the study, subjects performed seven different offensive maneuvers selected by TAC: Hi Yo-Yo, Lo Yo-Yo, Quarter Plane, Lag Roll, Immelmann, Barrel Roll, and Lead Turn (Figures 1-7).

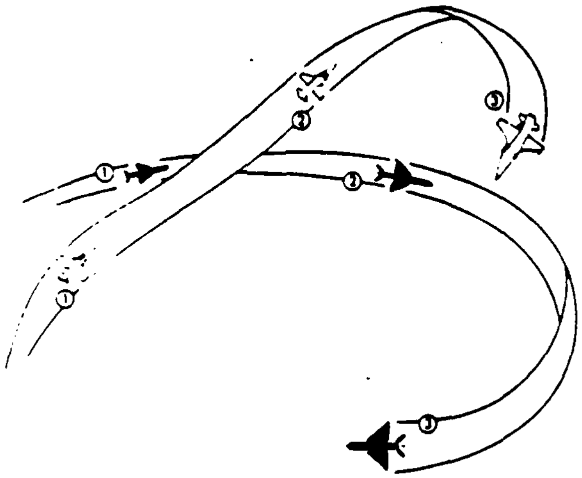


Figure 1. **High Yo-Yo Air-to-Air Maneuver.**

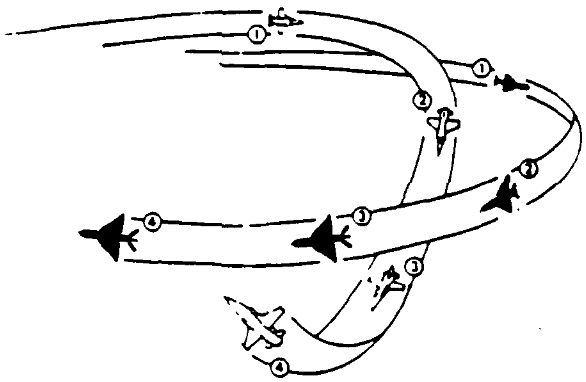


Figure 2. **Low Yo-Yo Air-to-Air Maneuver.**

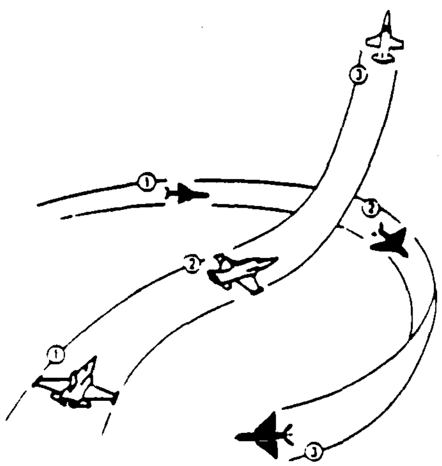


Figure 3. **Quarter Plane Air-to-Air Maneuver.**

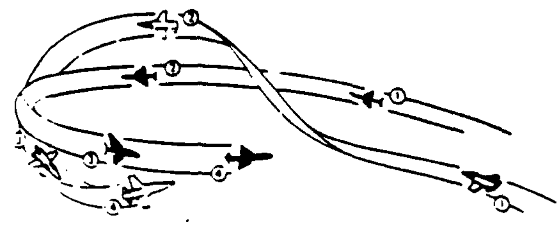


Figure 4. Lag Roll Air-to-Air Maneuver.

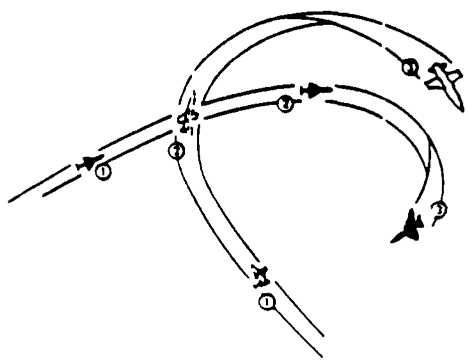


Figure 5. Immelmann Air-to-Air Maneuver.

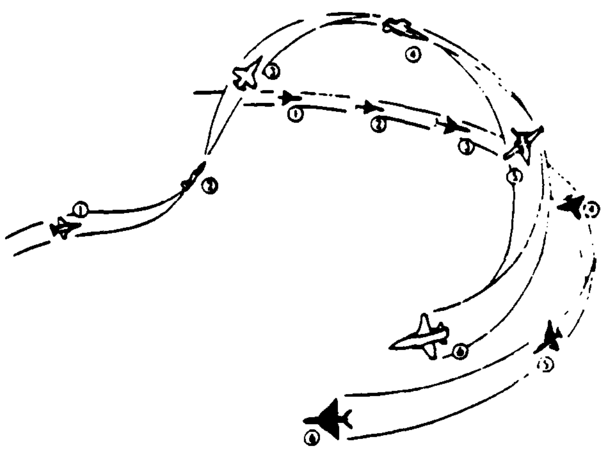


Figure 6. Barrel Roll Air-to-Air Maneuver.

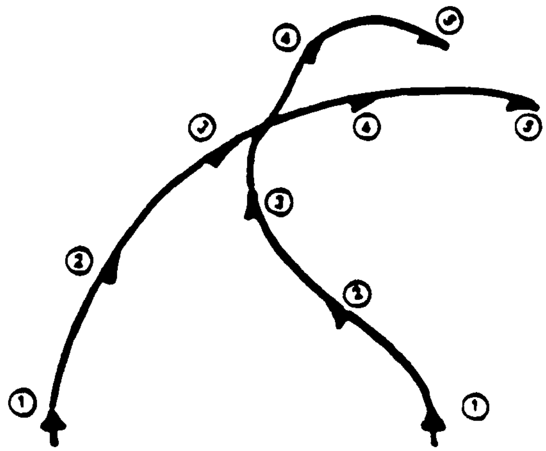


Figure 7. Lead Turn.

The High Yo-Yo, Low Yo-Yo, Quarter Plane, and Lag Roll maneuvers were initialized with the attacking aircraft 5,000 feet behind the target and very slightly offset to the side. The attacker was at 475 knots indicated airspeed (KIAS), the target was at 400 KIAS, and both aircraft were at 10,000 feet above ground level (AGL). Starting from this position, the attacking aircraft maneuvered to attain the desired aspect and angle-off parameters for the briefed maneuver, as shown in Figures 1 through 4 on pages 4 and 5.

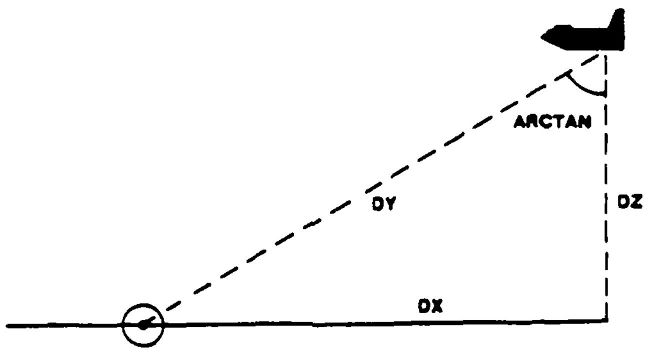
The Immelmann and Barrel Roll maneuvers were initialized with the attacking aircraft 3 nautical miles behind the target and offset 30 degrees to the side; both aircraft were at 400 KIAS and 15,000 feet AGL. As before, the attacker maneuvered to attain the position and parameters for the briefed maneuver, as shown in Figures 5 and 6 on page 5.

The lead turn was initialized with the attacker and target lined abreast and 9,000 feet apart; both aircraft were at 15,000 feet AGL and 475 KIAS. Once again, the attacking aircraft maneuvered to attain the position and parameters for the maneuver, as shown in Figure 7 above.

Procedure. Each subject was briefed on the purpose of the study and the types of maneuvers to be performed. Initial conditions for each maneuver and conventional tactics were discussed with each pilot to ensure that each had basic knowledge of air-to-air maneuvers. Each subject was then allowed to "free fly" for 5 to 10 minutes to get accustomed to the simulator. Practice target passes were allowed, but without any preset positioning. Once the subject felt comfortable in the simulator, data collection was begun. Data collection lasted approximately 1 hour per subject.

Subjects performed five trials of each air-to-air maneuver. Task order was randomized across subjects to compensate for practice and difficulty effects. The design of this portion of the study utilized a computer-driven target aircraft and the subject's aircraft. Both aircraft were initiated at altitudes, airspeeds, and relative positions appropriate for the maneuver (task) to be performed. The target flew forward for 5 seconds and then executed a continuous 3g turn to the right or left. For each trial, the aircraft were reset to the appropriate initial conditions for the maneuver. The simulator was frozen in the reset position until the subject was reminded of the task and flight parameters. When a trial was completed, the visual display was blacked out while the aircraft positions were reset. During each trial, the subjects were asked to fly the maneuver to the best of their ability and get into a firing position. They were allowed to use guns or radar-guided missiles to shoot at the target aircraft. Each trial was terminated after firing position was established or a shot was fired. Verbal feedback was provided as to hit or miss immediately after each shot was fired. The length of each trial depended largely on the proficiency of the pilot in maneuvering into a firing position. Trial length was approximately 45 seconds.

Performance Measurement. Data were collected on the target position (azimuth and elevation) relative to the standard pilot eyepoint. By continuously recording the target position at 30-Hertz (Hz) intervals, a plot was created of the target's path as it migrated through the pilot's FOV during the performance of each task. Target position was calculated (see Figure 8) by finding the distance and orientation of the aircraft to the target. These calculations took into consideration the pitch, roll, and yaw of the aircraft. Figure 9 illustrates a sample target migration plot of the air-to-air maneuvers. Target migration was defined as the movement of the target position relative to the standard pilot eyepoint. By collecting data that showed the position of the target throughout the maneuver, it could be determined what FOV was used during each task. This did not indicate where the pilot was actually looking, but merely the position of the target on the visual display. It was also possible to overlay proposed visual system dimensions and thus determine when the target would be within the dimensions of the system and when the target would be out of the pilot's FOV. This approach did not indicate what the impact of an LFOV would be on the pilot's performance, but did provide a baseline for proposing fixed-LFOV dimensions.



AZIMUTH = 90.0 - ARCTAN (DX,DY)

ELEVATION DT = ASQRT ((DY*DY) + (DY*DX))
ELEVATION EL = ARCTAN (-DX,DT)

Figure 8. Calculation of Target-Pilot Eyepoint.

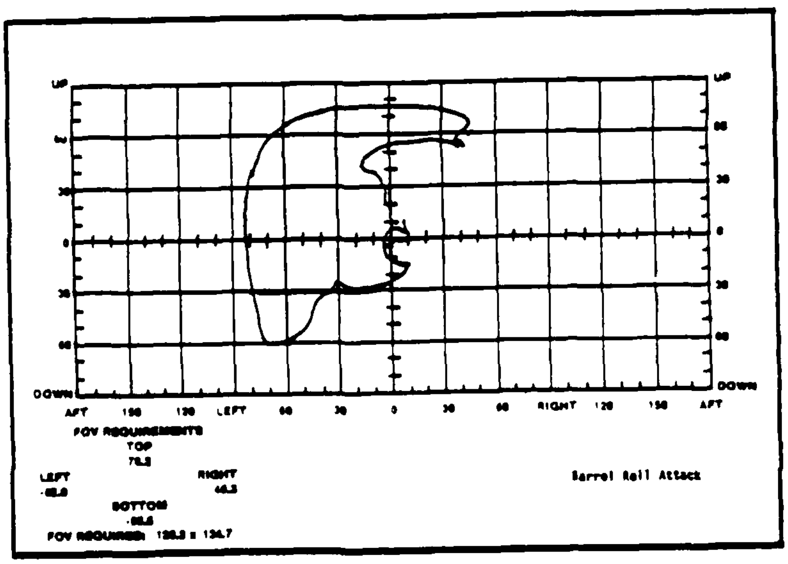


Figure 9. Air-to-Air Target Migration Plot.

Results and Discussion

The FOV used for each air-to-air maneuver was determined from the maximum and minimum azimuths and elevations of the target. Confidence levels were computed at the 90% and 95% levels for right, left, up, and down dimensions (Tables 1 and 2). Absolute values of these dimensions were combined to determine the azimuth and elevation used for each task. These dimensions showed that the horizontal and vertical axes were not symmetrical about the pilot's eyepoint. The maximum FOV dimensions were averaged over all subjects for all trials. Computation of the confidence interval took into consideration subject-to-subject and trial-to-trial variability. A diagram of the maximum FOV used for the air-to-air maneuvers is illustrated in Figure 10 for the 90% and 95% confidence levels. A 90% (95%) confidence level indicates the FOV required for the target to stay within the pilot's FOV 90 (95) trials out of 100. At the 90% confidence level, the seven air-to-air maneuvers used a total FOV of 171° x 133°. This may be divided into -100° left, 71° right, 75° up, and -58° down. The FOV at the 95% confidence level yields an overall 185° x 143°; specifically, -105° left, 80° right, 80° up, and -63° down. It should be emphasized that these results were obtained from experienced F-16 pilots and should not be generalized beyond that population.

Table 1. **Air-to-Air Field-of-View Dimensions (90% Confidence Level)**

Maneuver	Left	Right	Up	Down	Field of view AZ		EL
Low Yo-Yo	-37	37	52	-28	74	x	80
Immelmann Attack	-52	25	72	-16	77	x	88
Lag Roll	-47	46	63	-34	93	x	97
Hi Yo-Yo	-72	30	46	-54	102	x	100
Lead Turn	-79	69	67	-54	148	x	121
Barrel Roll Attack	-79	71	71	-57	150	x	128
Quarter Plane	-100	50	75	-58	150	x	133

Table 2. **Air-to-Air Field-of-View Dimensions (95% Confidence Level)**

Maneuver	Left	Right	Up	Down	Field of view AZ		EL
Low Yo-Yo	-42	41	58	-31	83	x	89
Immelmann Attack	-56	30	75	-19	86	x	94
Lag Roll	-52	49	67	-37	101	x	104
Hi Yo-Yo	-75	33	50	-58	108	x	108
Lead Turn	-86	76	71	-62	162	x	133
Barrel Roll Attack	-85	80	74	-61	165	x	135
Quarter Plane	-105	57	80	-63	162	x	143

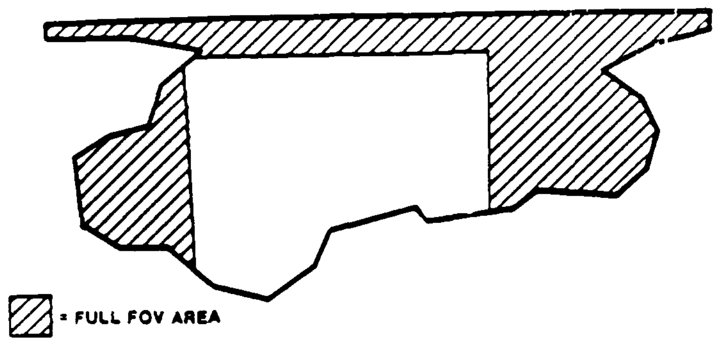


Figure 10. FOV Utilized for Air-to-Air Maneuvers.

Air-to-Ground

Method

Subjects. After participating in the air-to-air portion of the study, the five F-16 instructor pilots served as subjects in the air-to-ground portion of the study. The subjects had an average of 324 hours in the F-16, with a range of 80 to 800 hours.

Equipment. The air-to-ground tactical maneuvers were conducted in the AFHRL ASPT located at Williams AFB. The ASPT had a fully instrumented F-16 cockpit. The g-cueing was available but not used. The visual system of the ASPT was comprised of seven pentagonal, 36-inch, monochromatic cathode-ray tubes arranged around the cockpit, giving the pilot +110° to -40° vertical cueing and ± 150° of horizontal cueing, for a total of 150° vertical and 300° horizontal FOV. A more detailed description of the ASPT may be found in Gum, Albery, and Basinger (1975). The visual scene was computer generated and had the capability to display information for most pertinent ground references (mountains, runways, hangars, etc.) within a square area 1,250 nautical miles on each side. This study utilized the conventional gunnery range visual data base for the Eagle Range at Hill AFB, Utah. Target altitude was approximately 4,232 feet above mean sea level (MSL).

Task Descriptions. For this portion of the study, subjects performed seven different air-to-ground weapons delivery tasks. These tasks were 10°, 15°, 30°, and 45° Dive Bomb, 10° and 30° Pop-Up, and the Level Bomb. Weapons delivery was performed using the continuously computed impact point (CCIP) mode. Specifications for the initial conditions were provided by the 57th FWW, in coordination with the 58th TTW, Luke AFB.

For all Dive Bomb tasks, the subject's aircraft was initialized at a base leg position, displaced horizontally from the target by approximately 12,500 feet. Additional initial conditions for the Dive Bomb tasks were as follows: Level Bomb, 1,000 feet AGL at 415 KIAS; 10°, 3,200 feet AGL at 395 KIAS; 15°, 4,500 feet AGL at 395 KIAS; 30°, 7,700 feet AGL at 395 KIAS; and 45°, 13,500 feet AGL at 350 KIAS. A diagram of the Dive Bomb patterns flown is presented in Figure 11.

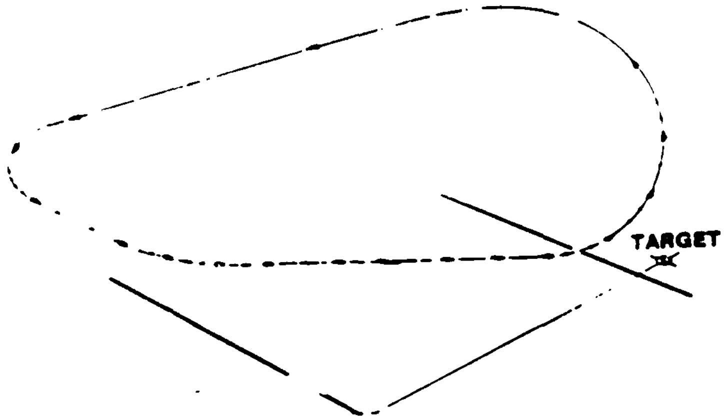


Figure 11. Dive Bomb Air-to-Ground Maneuver.

For the Pop-Up bomb passes, the subject's aircraft was initialized on a base leg position displaced horizontally from the target by approximately 15,625 feet. For both Pop-Ups the aircraft was initialized at 200 feet AGL at 350 KIAS. The pop-up point for the 30° Pop-Up was designated by a tower in the visual display. For the 10° Pop-Up, the pop-up point was delayed by 2 to 3 seconds from the tower. A diagram of the Pop-Up patterns flown is presented in Figure 12.

Figure 12. Pop-Up Air-to-Ground Maneuver.

Procedure. Subjects were briefed on the purpose of this portion of the study and the types of tasks to be performed. In addition, subjects were given a listing of the flight parameters for each weapons delivery task (Table 3). Subjects were allowed "free fly" time to become familiar with the simulator and make practice target passes, before data collection started. Data collection lasted approximately 1 hour 15 minutes per subject.

Table 3. Flight Parameters: Air-to-Ground Maneuvers

Task	Minimum Altitude (MSL)	Release Altitude (MSL)	Release Airspeed (KIAS)	Pull Apex (MSL)	Pull Down (MSL)
45° Dive Bomb	8,700	12,900	450		
30° Dive Bomb	5,700	7,900	450		
15° Dive Bomb	5,200	7,200	450		
10° Dive Bomb	4,500	5,100	450		
Level Bomb	4,400	4,400	450		
10° Pop-Up	4,500	5,300		6,700	5,500
30° Pop-Up	5,700	7,900		9,900	8,500

Each subject performed four trials of each weapons delivery task. For each trial, the aircraft was reset to the appropriate initial conditions, including position, heading, altitude, airspeed, power, and trim, for the maneuver (task) to be performed. The pilot was reminded of the type of task to be performed and the corresponding parameters, prior to release from freeze. Trials consisted of two types of patterns: (a) a complete box pattern including base leg, delivery, roll-out, recovery, downwind, crosswind, and return to wings level on base leg; and (b) a short pattern, ending with return to wings-level position on crosswind. Two trials of each type of pattern were flown for each weapons delivery task, with Type 1 trials lasting approximately 4 minutes and Type 2 trials lasting between 1 and 2 minutes. At the end of each trial, a tone sounded, and shortly thereafter, the subject flew into a cloud and the simulator was put on freeze. Subjects were asked to fly the maneuver to the best of their ability and to obtain the best bomb score they could.

During each trial, subjects were asked to fly a complete, normal recovery after bomb release (4G pullup 2 seconds from pickle) and not to alter their flight path in order to check the bomb spot. A readout of the flight parameters (airspeed, altitude, dive angle, accelerometer, and bomb score) at the instant of the just-completed bomb release for each bomb run was provided on a cathode-ray tube located to the right of the ASPT cockpit. As in the air-to-air portion of the study, task order was randomized to compensate for practice and difficulty effects.

Performance Measurement. The data collected in this portion of the study were the same as for the air-to-air portion of the study. Figure 13 illustrates a sample target migration plot for the air-to-surface maneuvers, from base leg to the turn to crosswind. Automated performance measures included in the flight parameters in Table 3 were collected and stored at an iteration rate of 30 Hz. At the point of weapons release, bomb miss distance was recorded in addition to the flight parameters.

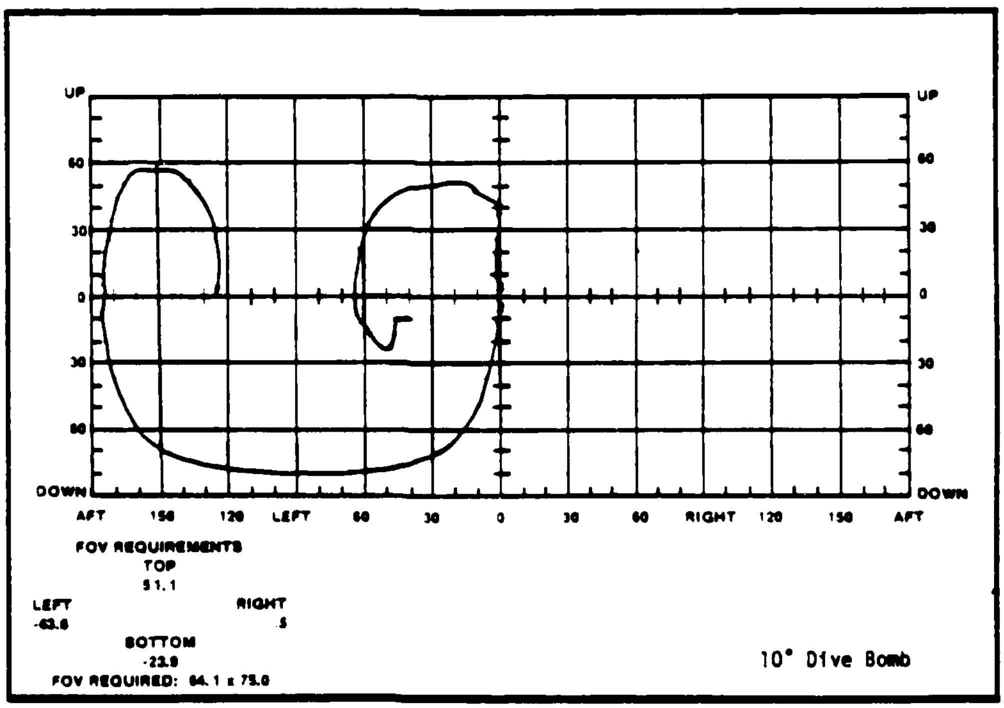


Figure 13. Air-to-Ground Target Migration Plot.

Results and Discussion

Results for the air-to-ground maneuvers were analyzed in the same manner as for the air-to-air portion of the study. Tables 4 and 5 provide the right, left, up, down, and total azimuth and elevation dimensions used at the 90% and 95% confidence levels, respectively. As in the air-to-air portion of the study, the resulting FOV used to perform the air-to-ground maneuvers is not symmetrical about the pilot's eyepoint. For the air-to-ground maneuvers, much of this condition is due to the left-hand direction of the maneuver. A diagram of the maximum FOV used for all of the air-to-ground maneuvers is illustrated in Figure 14 for the 90% and 95% confidence levels. At the 90% confidence level, the seven air-to-ground maneuvers used a total FOV of 93° x 125°. This may be specified as -78° left, 15° right, 70° up, and -55° down. The FOV at the 95% confidence level yields an overall 96° x 131°; specifically, -79° left, 17° right, 73° up, and -58° down.

Table 4. **Air-to-Ground Field-of-View Dimensions (90% Confidence Level)**

Maneuver	Left	Right	Up	Down	Field of view AZ		EL
Level Bomb	-59	1	53	-11	60	x	64
10° Dive Bomb	-64	1	50	-16	65	x	66
10° Pop-Up	-63	5	54	-23	68	x	77
30° Dive Bomb	-69	5	55	-38	74	x	93
15° Dive Bomb	-72	10	58	-48	82	x	106
45° Dive Bomb	-72	10	54	-55	82	x	109
30° Pop-Up	-78	15	70	-44	93	x	114

Table 5. **Air-to-Ground Field-of-View Dimensions (95% Confidence Level)**

Maneuver	Left	Right	Up	Down	Field of View AZ		EL
Level Bomb	-60	2	56	-11	62	x	67
10° Dive Bomb	-65	2	50	-17	67	x	69
10° Pop-Up	-64	6	57	-24	70	x	81
30° Dive Bomb	-71	5	57	-40	76	x	97
15° Dive Bomb	-74	13	61	-53	87	x	114
45° Dive Bomb	-74	11	56	-58	85	x	114
30° Pop-Up	-79	17	73	-45	96	x	118

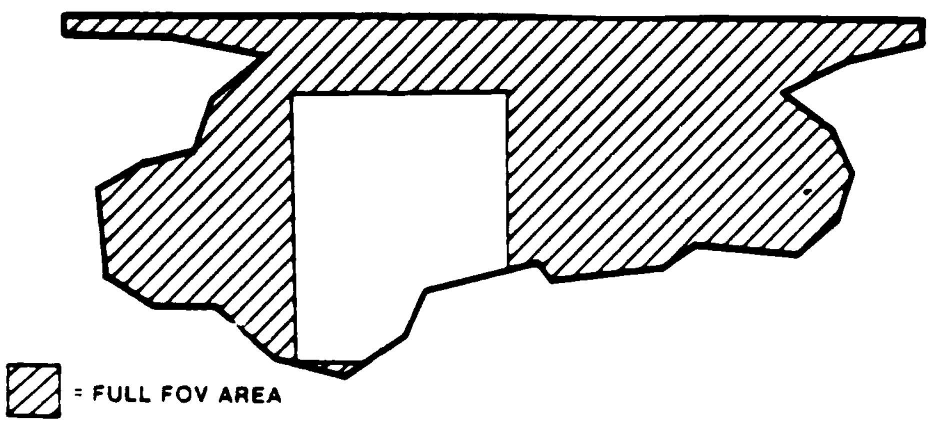


Figure 14. **FOV Utilized for Air-to-Ground Maneuvers.**

III. LIMITED FIELD OF VIEW

Objective

In addition to assessing the FOV required to perform various maneuvers, it was possible to mask the visual system of the ASPT to evaluate the effect of a fixed LFOV on air-to-ground weapons delivery performance in a tactical range environment. By using the technology available on the ASPT to reduce the visual system to the dimensions being considered for procurement, a preview of pilot performance could be investigated. The masking dimensions chosen were similar to those of limited visual displays currently being considered for procurement by TAC.

Method

Subjects. The subjects used in the WFOV condition were also used in the LFOV condition.

Equipment. The ASPT, configured as described in the air-to-ground section, was also used for this portion of the study. In addition, the visual system was modified to include a masking (electronic reduction) of the FOV in multiple-window configurations. The technology to limit (mask) the FOV in the ASPT was developed in support of previous research and allowed the horizontal and vertical visual scene to be altered to any desired dimension (Monroe et al., 1978). When this technology was used, the visual scene was reduced to the proposed LFOV dimensions (160° x 60°), to provide a preview of pilot performance in this size visual environment for air-to-ground tasks. For this portion of the study, the FOV was masked to ±75° horizontal dimensions and + 20° to - 30° vertical dimensions, for a total of 150° horizontal x 50° vertical (Figure 15). There were no visual cues available to the pilot outside of the masked area. The maximum dive angle of 45° required 50° of visual down display to retain the target and horizon during the bomb delivery. The minimum dive angle was a Level Bomb pass, requiring only 10 degrees down to retain the target and horizon during the bomb delivery. Three tasks (Level, 10° and 15° Dive Bombs) allowed the pilot to see the target continuously, whereas in four tasks (30° and 45° Dive Bomb, 15° and 30° Pop-Up), the target was intermittently in the pilot's visual field.

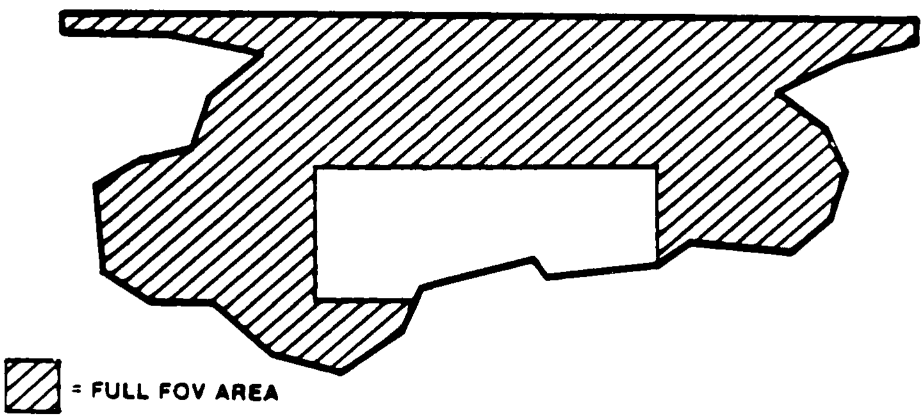


Figure 15. Limited Field of View.

Procedure. Data for the LFOV portion of the study were collected on the same day as the WFOV data. The procedure for data collection during the LFOV condition was identical to the WFOV condition described earlier. Each subject participated in two experimental sessions; approximately 1 hour of data collection was under the WFOV condition previously described, and approximately 1 hour under the LFOV condition, with an hour of rest in between. The order in which the FOV condition and tasks were administered was randomized to compensate for practice effects.

Performance Measurement. Distance, in meters, from bomb impact point to the target was the principal dependent variable measured. Ground tracks and target migrations produced in the WFOV condition were also compared to those produced in the LFOV condition, to ascertain any differences in flight characteristics due to the FOV condition. In addition, an interview at the completion of data collection provided subjective data from each subject, the results of which are summarized in Appendix A.

Results and Discussion

Table 6 shows the mean value for each of four dependent variables associated with bombing as a function of field of view and maneuver. As you can see, field of view affected both bomb miss distance and release altitude. Bomb error was consistently lower and pilots released their bombs at consistently lower altitudes with the WFOV than with the LFOV. Table 6 does not indicate that field of view had any consistent effect on either dive angle or airspeed.

Table 6. **Mean Performance as a Function of of Maneuver and Field of View**

Dependent variable	Field of view	Maneuver: Level bomb	Dive bomb 10°	Dive bomb 15°	Dive bomb 30°	Dive bomb 45°	Pop-Up 10°	Pop-Up 30°	Mean
Bomb Miss (Meters)	Limited	13.2	8.6	11.4	6.8	13.8	9.8	9.8	10.5
	Wide	11.4	6.2	7.8	8.0	10.2	7.4	6.4	8.2
Dive Angle (Degrees)	Limited	2.6	12.6	19.8	34.0	44.8	12.6	26.6	21.9
	Wide	2.8	10.8	17.8	32.2	44.6	13.8	29.4	21.6
Airspeed (KIAS)	Limited	444	452	448	452	463	464	441	452
	Wide	421	451	457	450	472	452	444	450
Altitude (Feet AGL)	Limited	301	1198	2161	4046	7963	824	2491	2712
	Wide	260	855	1621	3547	7691	806	2423	2458

The performance variables shown in Table 6 were tested for statistical significance using a multivariate randomized block factorial analysis of variance, with subjects as the blocking variable. This analysis indicated that field of view significantly affected both bomb miss distance ($F = 4.93$, df = 1,52, $p < .05$) and altitude at bomb release ($F = 4.55$, df = 1,52, $p < .05$) but had no significant influence on either dive angle or airspeed at bomb release. The analysis also indicated no interaction between field of view and maneuver on any of the four dependent variables associated with bombing performance ($p > .25$). In addition, performance also varied significantly between pilots and maneuvers ($p < .05$).

Target migration plots were produced for both the LFOV and WFOV conditions. From these plots, the maximum target migration in each direction (right, left, up, and down) was determined. Analyses of these data showed target migration to the right to be significantly affected by FOV, being significantly less (at $p < .05$) in the LFOV. This is equivalent to stating that the pilots turned from base leg to final sooner in the LFOV than in the WFOV. Ground track plots and observations during the trials supported this finding. This effect was especially prominent on tasks where the target was not in the FOV at the beginning of the trial.

For certain tasks in the LFOV, such as the 30° and 45° Dive Bombs, and 10° and 30° Pop-Up maneuvers, the target was not in the FOV during the base leg portion of the trial. Some of the subjects attempted to compensate for this inability to see the target by periodically dipping the wings to bring the target into view. One subject adjusted his heading away from the target to give himself more time to locate and line up on the target after the turn to final. Although the target was sometimes out of view, numerous other visual cues which could be used to determine the approximate location of the target were present even in the LFOV. A more concealed target could conceivably result in very different performance data.

IV. CONCLUSIONS

The purpose of this effort was to determine the FOVs required in a flight simulator to perform specified air-to-air and air-to-ground tactical maneuvers and to evaluate the effect of limiting FOV on performance of the air-to-ground maneuvers. Previous research focused primarily on basic flight maneuvers, such as takeoffs and landings, whereas this R&D incorporated more complex maneuvers, such as the Immelmann and Pop-Up bomb attack. FOV requirements were found to vary widely between air-to-air and air-to-ground maneuvers; in nearly all cases, the FOV requirements for air-to-air maneuvers were symmetrical and those for the air-to-ground maneuvers were skewed to one side (in this case to the left, since these maneuvers incorporated a left roll-in to the target). These results are in agreement with the conclusion reached by Irish et al. (1977) that the FOV variable has a tendency to have maneuver-specific effects. Another factor that can affect the accurate measurement of the FOV required is the initialization point. For this study, pilots were initialized on downwind, requiring them to turn to final and release weapons. Initializing the pilots on a crosswind position would require them to make a turn to downwind with little or no visual cues as to the location of the target.

The results of the bombing portion of this experiment indicate that training developers need to match the simulator task training with simulator field of view. Although pilots were able to deliver bombs with the LFOV, the accuracy of their bombs and their flight paths were different in the LFOV and WFOV conditions. If we assume that the WFOV condition produced performance closer to actual flight performance than did the LFOV, this experiment shows that an LFOV may alter the manner in which pilots perform specific tasks. Such performance differences should be even larger for students who do not have the instructor pilot's experience and correspondingly high level of knowledge regarding bomb delivery. Therefore, it may not be possible to train complex tactical tasks the same way in an LFOV simulator as in either a WFOV simulator or the actual aircraft.

A significant problem encountered in this effort was the identification, measurement, and evaluation of appropriate performance criteria. Early in the study, it became obvious that although the pilots were briefed on the optimum parameters (such as airspeed at bomb release, angle-of-attack, altitude at release) for each maneuver and were asked to fly as close to those parameters as they could, in their minds the only criterion of performance was the bomb score. If the pilot successfully dropped a bomb close enough to the target to score a "kill," the trial was a success even if it meant turning a 45° dive bomb pass into a 32° dive bomb. Based on this criterion, nearly all trials by all subjects in both conditions would be considered successful

(277 out of 280 trials). As a result of this pilot-imposed criterion, a great deal of variability was introduced into the performance data and may have masked the influence of Simulator FOV. Future research might be able to minimize this difficulty by reducing the number of tasks studied and increasing the number of trials per task.

The Bottom Line. The tasks to be trained are the critical factor in determing the appropriate simulator field of view. Previous research has shown that many basic flight tasks can be trained in LFOV simulators. The target migration analyses performed as part of this experiment show that targets migrate over a fairly large visual area during many tactical air-to-air and air-to-ground tasks. In addition, the bomb delivery portion of this experiment shows that restricting the simulator FOV causes experienced pilots to alter their flight paths. Actual transfer-of-training experiments are required to determine if there are significant differences between LFOV and WFOV simulators in their ability to support the training of specific tactical tasks.

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APPENDIX A: PILOT INTERVIEWS AND COMMENTS

1. How difficult was it to fly air-to-air maneuvers in the SAAC F-4?

scale	1	2	3	4	5
	easy				very difficult

mean response: 2.8

2. Do you feel the LFOV affected the way you flew the patterns? All five pilots reported that they felt the LFOV affected their flight pattern.

If so, how?

a. When they lost the visual of the target at roll-in, pilots had a tendency to float the turn in, instead of bringing the nose down to the target.

b. Pilots indicated they had to use more guesswork for leadpoints as to when to turn in to the target.

3. Do you feel you used more instrument references with the LFOV than with the WFOV? Four out the five pilots answered "yes."

4. Rate each task below as to how much you feel the LFOV affected your performance.

scale:	1	2	3	4	5
	none				could not do task

mean responses:
45° Dive Bomb -- 3.8
30° Dive Bomb -- 3.2
15° Dive Bomb -- 2.8
10° Dive Bomb -- 2.6
Level Bomb ----- 2.4
10° Pop-Up ----- 3.2
30° Pop-Up ----- 3.8

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